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## **Aspects of Transfer of Gothic Masonry Vaulting Technology to Greece in the Case of Saint Sophia in Andravida**

Dimitris Theodossopoulos  
*University of Edinburgh, UK*

**ABSTRACT:** The Frankish Cathedral of Saint Sophia in Andravida, in Elis, Greece was an emblematic construction of the crusaders Princes of Achaia that used cross vaults in a manner not attempted before in a territory dominated by Byzantine architecture. Analysis of the construction and structural behaviour shows careful application of rather archaic vaulting techniques and patterns. A key question is how such schemes and technology were transferred into a politically and culturally foreign, almost hostile environment. Comparison with contemporary developments in Byzantine architecture shows research into the spatial role and structural efficiency of vaults and domes but not similar to the gradual disintegration of the envelope in Gothic architecture. It is therefore important to identify the role of patrons and masons in the design of the church. Study of the construction and structural performance using Finite Element analysis showed a well executed conservative design with limited direct input from local practices.

### **INTRODUCTION**

The Frankish occupation of mainland Greece following the fall of Constantinople in 1204 to the Fourth Crusade lasted until the beginning of the 15th century and the Principality of Achaia or Morea (1205 - 1430) at the Peloponnese was the strongest state created then. This kingdom marked its presence not only with military infrastructure, like the castles of Chlemoutsi (Claremont) or the early Mystras but also through the construction of Catholic churches and abbeys. This period has been traditionally considered in Greece as a foreign and hostile occupation and essentially Western building techniques and design cultures had to be exported to a quite distinct environment dominated by Byzantine architecture, apparently Gothic elements are applied outside the main domain of the movement. It is very interesting therefore to examine possible influences and exchanges through the architecture and particularly the construction technology and structural design of the churches, in other words whether there were technology transfers between the cultures and how successful they were.

This work attempts to assess such issues through the study of stone vaulting in churches, which can be considered as the key element of the structural and spatial layout of these Gothic-like buildings. Churches may have been the most contentious expressions of the Frankish architecture due to the dogmatic and political differences between the Roman and the Eastern churches and the turmoil of the Fourth Crusade and this allows the possible exchange between the two cultures to be clearly tested.

So far, the study of the architecture of Frankish Greece has focused on either the Morea (Bon 1965) or the role of monastic orders (Kitsiki 1979) and the design and history of key buildings have been discussed as part of political or religious processes. Grossman (2004) presents a particularly interesting thesis in her attempt to discuss the period as an encounter between Western and Byzantine practices, leading to a new hybrid architecture. This period was however the only expression of Gothic architecture in Greece and for political or cultural reasons it left no further influence in Byzantine architecture once the Frankish kingdoms disappeared, neither in the Peloponnese or the re-constituted Byzantine Empire.

In this work, the study of construction systems and the role and efficiency of the structural scheme in the design of such buildings will be the main tools in the study of exchanges and transfer between the two cultures. Saint Sophia in Andravida, the most prominent of the new Frankish churches of Morea (including the Zaraka Abbey in Stympalia or Our Lady in Isova) will be the case study as the vaults above the choir are still intact and well

documented. The critical analysis of the systems will be supported by structural assessment of their performance, as well as discussion of the design process. The application of a foreign design that was imported by the new patrons had to be conditioned by the collaboration with masons and the use of local human and material resources (Ousterhout 2008), and this study will contribute into the further understanding of design process in Medieval Europe, where both culture belonged.

## FRANKISH AND BYZANTINE ARCHITECTURE

### Key architectural and construction characteristics of the two cultures

The contact between the two cultures in the Morea came in a period of cultural and architectural changes for both. Gothic style, technology and architectural authorship was establishing in the construction of the large scale cathedrals in France (for example Chartres (1194-1264) or Amiens (1220-1266), with technical advancements in the efficiency of structural schemes in stone architecture and especially the vaulting systems and vertical load-bearing elements (wall elevation and piers). Ribs became gradually important in the geometric resolution and construction of the difficult joints at the intersecting webs in a cross vault and eventually, together with the shafts of the piers, were used to visually unify the entire structure (concordance). It is interesting therefore to investigate the degree these new techniques and attitudes were transferred in the Morea.

Mainland Greece on the other hand was at the end of the Middle Byzantine period (843 – 1204), a time when the area gained once again its importance within the Empire (Mango 1978). The architecture at the end of this period was of a relatively small and intimate scale, and in the case of churches these were either private aristocratic foundations (like the Pantocrator monastery in Constantinople) or parish centres. The character of the architectural research of the period is the elaboration around a church type which in the context of the liturgical aspects of the Orthodox Church can be considered as perfect and completed (Mango 1978, Ousterhout 1999).

The Peloponnese would usually only receive architectural and technological trends that were developed in other centres of the Empire. Essentially, Byzantine churches are designed around their interior space and the strongly plastic treatment of the exterior reflects the internal divisions and roofing systems (Mango 1978). Even in the smaller churches of the area there is an attempt to form a hierarchy between the dome of the nave and the squinches or other elements that shed its weight and thrusts towards the vertical structure. The notion of an established, almost perfect type of layout is also a result of the spiritual stability the Eastern Christian society has reached after the civil conflict of the Iconoclastic Controversy and this is expressed in conservatism in the construction technology.

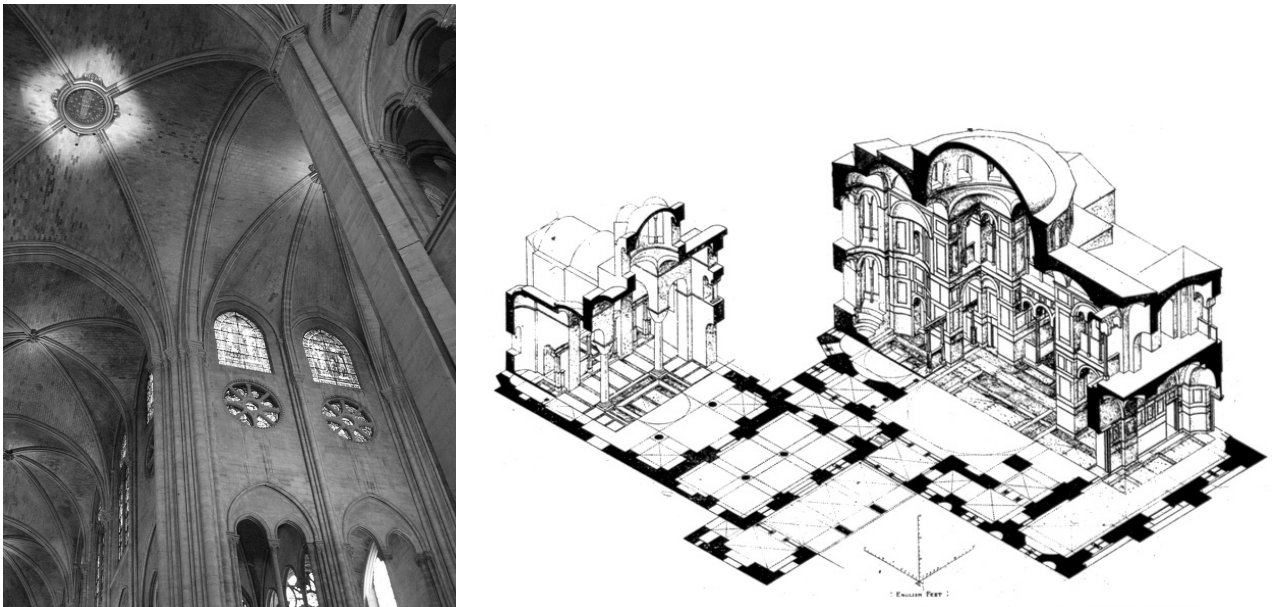


Figure 1: Comparison between the structural schemes of Gothic (Notre Dame, Paris; 1163-1225) and Byzantine churches; (Hosios Loukas, Greece; Fletcher 1996)

Fundamental differences, due to ritual, characterise the space and, to a certain degree, construction. The emphasis on processional axes focusing at the single point of the altar in the West was already in contrast to the centralised space of the Byzantine church that enhanced the experiential participation required for the mystical events of the Liturgy. The roof in a medium-sized Latin church did not have to be in stone vaulting if relatively long timbers were available and the mendicant monastic orders would initially prohibit the expensive stone vaults as a sign of material poverty. Rib vaults were already experimented before this period (Theotokos at Hosios Loukas) but they were exceptional. Hierarchy in the construction scheme was therefore important

but expressed with different means. Skeletal approach and channelling of the loads through groin vaults, squinches and point supports was tested in Greece, as in the highly elaborated scheme of the Katholikon of the Hosios Loukas (ca 1012) but it never led to the gradual disintegration of the envelope as in Gothic architecture (Fig. 1). However, studies in the last years have demonstrated that basilican layouts were also popular in Byzantine architecture, and mostly were used as metropolitan churches (Gioles 1987).

### Frankish Architecture in the Morea

The Principality of Achaia or Morea lasted between 1205 and 1430. The Villehardouin family, the original conquerors, controlled the state until 1278, when power was taken by the Angevins of Naples and finally between 1364 and the dissolution by the Greek Despotate of Mystra in 1430 it was ruled by pretenders and usurpers (Bon 1969). Andravida (Andreville) was the capital, and the Palace and the Cathedral of Saint Sophia were built there, probably after 1263, as a monastic foundation (Dominican) that combined civic functions like the Great Court. Other major new churches of the Principality include the Cistercian monastery at Zaraka (Saracez) in Stymphalia (Fig. 2), that existed between 1224-61, and the Monastery of Notre Dame at Isova, which was followed by the church of St. Nicholas after it was burnt in 1263.

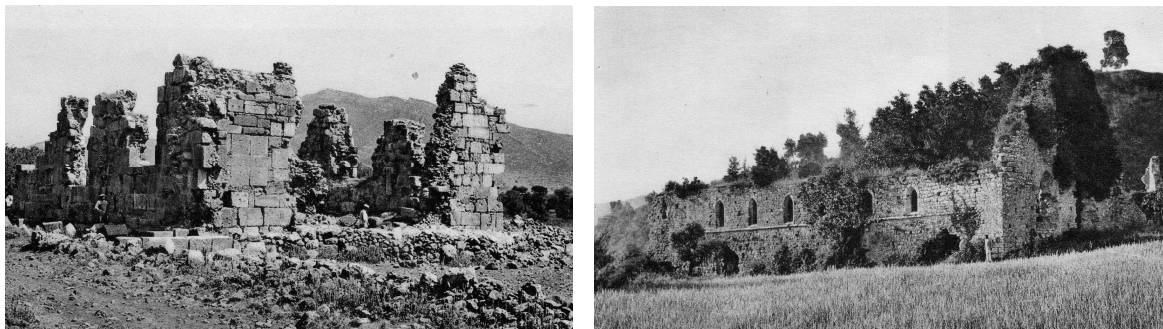


Figure 2: Ruins of the church of the Abbey of Zaraka (left) and Our Lady in Isova (right); (Bon 1969)

These churches were of larger scale than their Byzantine contemporaries and they had longitudinal basilican layouts, with variations in the tripartite arrangement. Pointed arches (at the windows) and shafts are the evident elements of Gothic building techniques. The coursed rubble walls, with the inclusion of various forms of ashlar blocks still create here however a thick and solid envelope with small openings that would let in only a small amount of daylight. Often the shafts have been detached from the walls indicating a decorative use and lack of treatment as integral part of the construction process.

The churches are all in a ruinous state that does not provide information on the nave wall elevations or the presence of stone vaulting and therefore the design cannot be assessed in terms of concordance with the shafts, apart from Andravida. Any possible stone vaulting may have been sustained by only pier buttressing arrangements and there may have been compound piers in Zaraka. The intact choir in Andravida shows an archaic treatment of the ribbed vaults as the ribs spring from corbels at their impost. Since they are the only true ribbed vaults from this phase, vaulting technology will be discussed in more detail in the analysis of the case study and in the context of other major structures like the unribbed barrel vaults at the Castle of Chlemoutsi.

### Patronage and design

Clearly these were buildings commissioned by the new rulers of the Peloponnese to serve both religious and propaganda purposes. All three major churches are of monastic origin and had to primarily fulfil the Rules of their orders while Andravida had also to meet the aspirations of the Princes and express its location in an urban context. These conditions imported by the new, foreign ruling class met a local design culture that was less formulaic about styles, placing more emphasis on the iconographic programme. Construction practice was based on rubble and brick to provide a solid envelope and it had not been necessary to develop their structural efficiency and load-bearing capacity neither for vertical or shell loads. Moreover, there is much less emphasis on precision in the layout and construction programme of a Byzantine church.

Robert Ousterhout (2008) believes it is important to discuss the creation of historic architecture at the Eastern Mediterranean through the role of the architect and the mason. He identifies three principles in their relationship with the patron of the building which can apply in the following manner in the Morea:

Architectural style does not correspond directly to the construction technology used. Shafts were usually attached to a heavy stone masonry wall and were not treated as a visually or technically unifying element. In Andravida, brick was used to build vault types associated with stonework.

Patrons do not share the same cultural experiences as the artisans or even the masons. Even if the patrons had brought their own masons from France they would both operate outside the cultural context of their origin. The Villehardouins originated from Champagne and they may have been inspired by the architecture of the neighbouring Burgundy, which also played a key role in the development of Gothic: wide main volumes, bounded by narrower lateral spaces, small openings and controlled lighting effects, and structural conservatism (Branner 1960). The design may have also been inspired by the architecture of the Angevin Kingdom of Naples (Sheppard 1985), due to political affinities with the Principality.



Architecture is eventually a group endeavour. The patrons would have to employ workforce with very different practices and ways of communication. However, the above mentioned context would have favoured the construction of the main structure using local workforce (as in Zaraka) and the insertion of more "modern" elements (suited the aspirations of the patrons) using specialist artisans who could have come from France or Western centres.

Antoine Bon distinguishes these churches, which were built *ex novo* in a new style, from others that were probably under construction at the time and were finished with Gothic elements like pointed windows, as in the case of the Vlachernae Monastery (Bon 1969). As mentioned earlier, local practices were less rigid than in the West and later insertion of elements would not have disturbed the progression of the design which was mainly carried out in-situ.

### Issues of technological transfer in Frankish Greece

In most Byzantine churches of the period the vertical walls follow the *cloisonné* pattern of framing often each stone block with bricks. This type of bond, together with the tri-partite apse (which suits Eastern rites better) and the use of brick masonry at the vaults are elements from this culture that can be identified in many of these churches. Heather Grossman (2004) made a wider syncretic study of churches from both rites of the period in an attempt to establish the case for a hybrid Moreote architecture that would serve both cultures and apart from these techniques there is some further evidence in the ornamentation of the churches (the use of crocket capitals). I believe however that such an exchange should have affected Byzantine churches in a more profound way, such as the development of more efficient construction techniques or an advanced structural articulation of the space that could be expressed with unifying elements similar to the role of the shafts. Examples of this approach like the later Paregoritissa in Arta (in the northern Despotate of Epirus) give clues of such an exchange but it is a very isolated example. It would be worthy to study this both as a technical problem as also in relationship with the patronage and the origin of these buildings.

Vaulting is a more interesting area to assess technological transfer and it is believed that as well as Andravida Zaraka had such roof (Campbell 1997). In both cases, ribs were added to the intersection after the webs were built and thus did not have a function during construction. In Byzantine domes and arches brickwork was used as it was a simpler material for their construction and adjustments of the form could be easily made. The joints however were too thick and mortar would take very long to set so the buildings could easily distort, therefore Western technology has overall produced thinner joints and load-bearing construction uses more ashlar. Vaulted structures, apart from benefits in roofing, were otherwise considered as expensive elements and mendicant orders professing poverty like the Dominicans would restrict their use only at the apse, as Andravida shows. Their advanced technology and articulated space qualities and possibilities could have been actively used by the patrons to promote the Principality and the Roman Catholic Church to both the working and the upper classes.

The application of the advanced yet impressive flying buttress systems did not occur anywhere in Latin Greece. This is a result of the fact that the scale of the churches and associated spans was eventually relatively small and the finances and the perceived animosity between the two communities did not produce the conditions for the application of such complex elements.

## THE CATHEDRAL OF SAINT SOPHIA IN ANDRAVIDA

### The design of the church and vaults

The most intact building of this group is Saint Sophia in Andravida, built as a Dominican abbey church that served also as the Cathedral of Prince Guillaume Villehardouin probably after 1263. Vaulting was used only over the east end (Fig. 3) while the tri-partite nave was enclosed by a timber roof, as the excavations by Sheppard (1985, 1986) confirmed the presence of rather slender single shaft columns at the gallery (Fig. 4). This was due probably not only to reasons associated with Dominican rules mentioned earlier but also to the fact that no further refurbishment of the church took place later, as the Angevins who effectively succeeded the Villehardouins after 1278 did not invest in the prosperity of Morea.

The study concentrates on the design and performance of the vaults as a further tool for the understanding of the entire design of the church. The high vaults are quadripartite ribbed cross vaults, made of brick and stone in course rubble (Fig. 3). The opening of the apse towards the nave is 6.65 m and the apse width *L* is about 7.7 m wide, with the first bay being 4 m long and the second 4.4m. It is difficult to assess the overall height of the apse, but what matters is the rise of the vault from the imposts to the keystone and this was assessed as  $F=5.73$  m (Traquair 1923). The vaults were designed following probably the third point rule for the profile of the inter-sections and the ribs, which were apparently built first in order to define the arrangement of the formwork. The resulting radius  $R=5.9$  m and this was used to trace the transverse arch towards the nave (triumphal arch). The longitudinal arches along the lateral walls are then projections of the diagonals on the wall plane.

The apse is flanked by ribbed vaults at the side chapels that resemble the Byzantine *pastophoria*, with overall dimensions in plan 3.95 x 3.65 m. They appear to abut the high vaults like flying buttresses as they counteract the line of thrust from the high vaults through their own thrust in combination with the spandrels, the fill at haunches and the transverse walls, which are rather thick (measuring between 0.94 and 1.02). Because of the difference in rise, maybe they were designed for this function and their role in containing the thrust will be as-

essed in the structural analysis of the high vaults. The thrusts of the vaults are further contained by a system of heavy pier buttresses applied at an angle at the corners of the apse (Fig. 4) and only a limited amount of the enclosing walls lets natural light in through pointed windows or lancets.



Figure 3: The choir of Saint Sophia in Andravida and the cross vaults (right)



Figure 4: Archaeological plan of the church; (Sheppard 1986)

Direct origins to either Burgundian or Angevin Gothic are not easy to establish. Similarity to the apse of San Lorenzo Maggiore (after 1270) in Naples (Sheppard 1985) might be deceptive as the original timber-trussed nave would enclose the chapels along the aisles as well and the springings of an arcade show there was no open transept. San Domenico Maggiore (1231-55) has concordance between the vault ribs and the shafts at the apse, but the exterior of the (polygonal) apse shows interesting similarities with the diagonal pier buttresses at the corners of the (flat) apse in Andravida. Overall, the design of the vaults here is plain, functional and well executed and probably the patrons had in mind further refurbishment and extension of the vaults to the nave.

### Construction

Byzantine cloisonné brickwork patterns were used in the Morea (see the Byzantine church in Mentzena) and here they are attempted systematically only as decorative elements at the choir. Externally, brick tiles were inserted probably at 1960's restorations (Sheppard 1985). Overall, the masonry is coursed rubble re-using ancient *spoglia* and most probably stonework was meant to be visible. The vaults are made from thin ceramic tiles or stone blocks, closely spaced and bonded with thin mortar joints in a regular pattern (Fig. 5). There is clearly care in the construction of the webs, reminiscent of the earlier vaults at the nearby Chlemoutsi Castle (1220-23). The Villehardouins showed they could invest in the quality of key elements of their buildings and employ masons who could support their aspirations.

It would make sense to form the edge of the transverse vaults, as mentioned before, by the projection of the ribs on the wall but it seems there was an effort to use the same radius as the ribs and this creates an awkward geometry which was not possible to materialise with the available techniques. The haunches had to follow a twisted pattern that hides behind the projection of the ribs and it was resolved by changing the coursing of the tiles and building a more solid cone (Fig. 6). Eventually, the vault was plastered and there are traces of colour used to create a geometric pattern imitating stonework on the lateral walls.



Figure 5: The masonry and ribs of the vaults in the choir (left) and section of the unribbed vaults in the Chlemoutsi Castle (right)

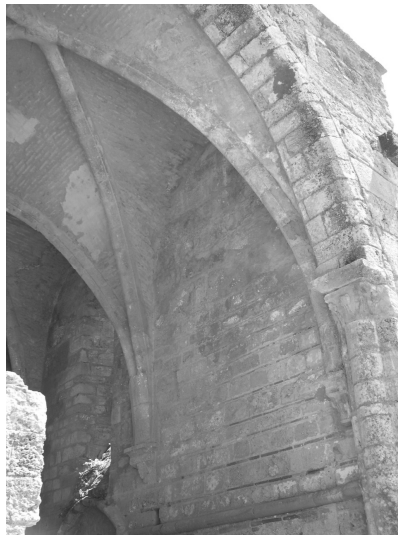


Figure 6: The springing of the outer vault of the choir



Figure 7: The fallen ribs at the vault over the north chapel

There is some sophistication in the construction of the vault, with careful adjustments and refined finishing of the elements, like the joining of the ribs on the corbelled support or the standardisation of the rib voussoirs. There is definitely an architecture that is generated from the pointed arch and is not making adjustments of the circular arch that was more in use in Byzantine vaults. In construction terms the haunches might have effi-

ciently reduced the span that was required for the formwork and the straight courses do not show any attempt to use domical arrangements for the units. However, the vaults do not represent the technical and aesthetic contemporary refinements of the type: the intersections along the groins are highlighted and strengthened by stone ribs of a heavy torus section (Fig. 5) but there is no attempt to unify the underlying space as these ribs do not extend as shafts to the elevation. Moreover, Sheppard (1985) believes the ribs were attached later on the groins, when also the chapels were added, and the fallen rib on the north chapel gives some indication on the detailing (Fig. 7). Although this needs closer inspection, the masonry along the intersections at the high vaults does not seem to be disturbed or re-worked and, apart from the difference in the length of the bays, the vaults appear to spring comfortably from the walls and the insertion of the ribs at corners avoid the distorted pattern of the chapels.

### The structural scheme

A Finite Element (FE) numerical model was set up in order to perform analysis of the structural behaviour of the vaults under their own weight and an attempt was made to simulate the support conditions. The vaults were simulated like shells with the program GiD (as pre-processors) and Abaqus as the FE analysis package and appropriate elements were used for the webs (shell) and the ribs and arches (3D beams) (Theodossopoulos 2003). This simulation is only an initial approach to assess the performance of the form, as the presence of fill at the haunches or the spandrel walls that support the roof can alter the stiffness. A uniform thickness of 250 mm was assumed and the masonry was considered as orthotropic, using values from the model for Holyrood Abbey in Scotland (Theodossopoulos 2003) due to similar masonry bond (elasticity modulus in stiffer direction along bed joints  $E1 = 4.9 \text{ kN/mm}^2$  and perpendicular  $E2 = 1.4 \text{ kN/mm}^2$ ). Linear elastic analysis under self weight  $24 \text{ kN/m}^3$  was performed and instability due to lateral spread of the supports was not assessed in this stage.

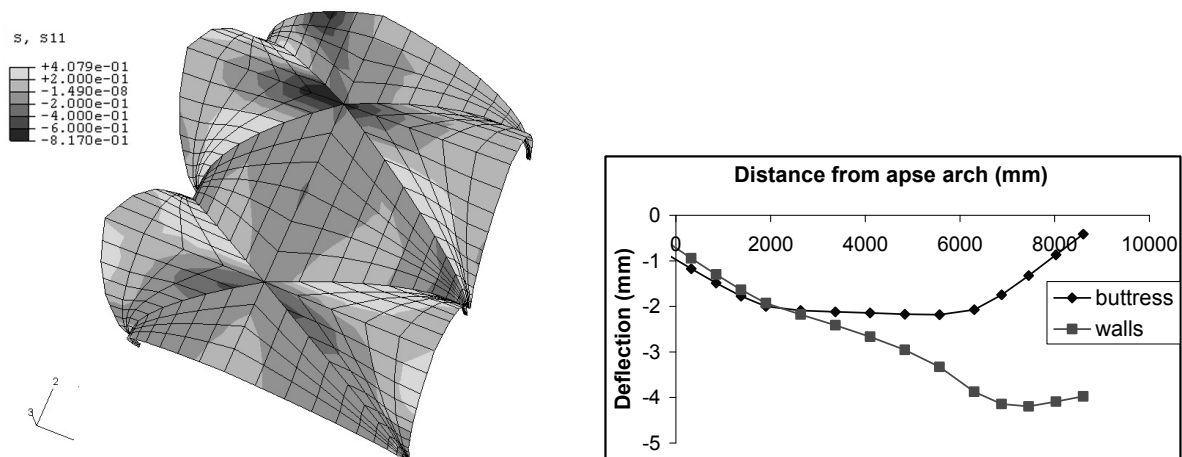


Figure 8: Structural analysis of the choir under self weight: transverse stresses at the extrados, without buttresses, in  $\text{N/mm}^2$  (left); deflections of the longitudinal vertex, with and without buttresses at corners (right)

The most crucial aspect is the simulation of the supports and the process discussed in (Theodossopoulos 2008) is followed. The walls along the sides and the east end were considered as deep arches running along the edge of the shell. The width of their cross section was taken as the thickness of the wall (1 m) and the depth was chosen as 1m as well in order to count for the presence of the lancet and pointed windows. The lateral chapels' function was applied as lateral constraint at the base of the first bay and initially the squint pier buttresses at the east end were not modelled.

The stresses and deflections (Fig. 8) are overall small but the geometry of the vault and its condition were modelled as regular and the deformation can be influenced by movement of the walls or irregularity of the masonry. Tensile stresses appear at the middle of the transverse webs, a pattern that is verified by cracks observed at a similar area today. The deflections of the longitudinal vertex represent the deformation of the vault and show how important the containment of the thrusts is for this scheme. Actually this effect is more crucial than the stiffness of the edges as the deflection at the east end is higher than the one at the arch of the apse ("walls" in Fig. 8) and only when the lateral movement is restrained ("butteress") the deflection reduces to levels similar to the arch. These two conditions are the bounds of the effect of the buttresses at the corners and more careful definition of their function by fine-tuning the stiffness of the support or modelling the piers will produce patterns within these bounds.

Finally, chapels were removed altogether in order to test the hypothesis that they were added later. The vaults would spread about 40 mm and max deflection of 21 mm would be strongly pronounced at the triumphal arch. This is a relatively large deformation (within the conditions of the analysis) that would have left a permanent effect the later additions could not cancel. Survey can once again clarify this hypothesis.

## ARCHITECTURAL EFFECT AND TECHNOLOGY TRANSFER

The form and role of these vaults belong to a spatial concept that is quite alien from liturgical practices in the local Greek Orthodox architecture, where space is not articulated by shafts and linear elements. The apse however indicates an aspect in common as solid walls and vaults were preferred that allowed only a limited and controlled amount of light and provided a thermally temperate environment. The last archaeological campaign (Sheppard 1985) identified a later phase of the Frankish design when openings at the apse would be regularised but also down-sized. This can show some influence from contemporary Byzantine tendencies for a more mystical and focused church environment and possible exchanges at spiritual and cultural level.

Regarding adaptations of the scheme, which may be a sign of mixture of Western architectural intentions with local building practices, a more detailed survey would allow the exact geometric scheme to be defined. It can also reveal any offset due to such adaptation or inexperience of masons that is not related to structural problems.

Finally, it has to be mentioned that no major Byzantine vaults or domes are situated in the area, with the closest being those of Hosios Loukas (in Phokis) and Daphni in Athens. As there is no evidence thus of earlier experimentation of masons and only limited use of cloisonné patterns, it is probable that local workforce was used as builders guided by masons directly associated with the patrons. It is also possible that a different mason, even coming from abroad like Burgundy or Naples, designed and supervised the vault

## CONCLUSIONS

Gothic Architecture is often considered as an advanced construction system that highly rationalised the use of stone masonry into slender and efficient stone skeleton schemes. This work aims to show the issues of transferring such schemes into areas with a less demanding emphasis on research and technical efficiency, as was Greece at that time. The constructional and structural analysis did not show any direct exchange between the two cultures but rather highlighted the successful efforts of the patrons and their masons in implanting Gothic ribbed vaulting in one of their major buildings. Measured survey of the building can fine-tune some of the implications of applying a foreign design in a foreign context while a closer analysis of vaulting techniques in important later Byzantine buildings as in Mystra could show possible effects of the presence of technically advanced systems in the region, like ribbed cross vaulting.

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